PhD Thesis Defense PETER SCHMIDT 'Exploring Intersubbands in 2D Materials'

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Tuesday, April 16, 10:00. ICFO Auditorium

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Transition metal dichalcogenides (TMDs) are semiconducting layered materials that can be isolated up to the limit of a single atomic layer. Next to graphene, they are some of the most intensively studied materials within the larger family of 2D materials. TMDs have been studied thoroughly for both their electrical and optical properties showing intriguing phenomena. All optical studies have so far been limited to the visible to near-infrared wavelength region,

exploiting interband transitions from the valence to the conduction band. This is surprising, since the two-dimensionality of TMDs gives rise to additional transitions within the conduction and valence band. These intersubband transitions typically lie in the mid-infrared to THz wavelength region and are a direct consequence of the quantum confinement of the charge carriers? wave functions in the out-of-plane direction, leading to quantized energy states. In systems such as III-V semiconductor heterostructures, intersubband transitions have been well studied and have led to the development of quantum cascade lasers and quantum well infrared photodetectors. Intersubband transitions in TMDs are particularly promising, as the layered nature of 2D materials leads to atomically sharp interfaces between different materials thus limiting the detrimental effects of interface roughness. Furthermore, due to the TMDs? weak van der Waals interactions in the out-of-plane direction, there are no lattice matching conditions. Intersubband transitions can therefore be combined with all kinds of two- and three-dimensional materials, including waveguides and cavities.
In this thesis, we explore intersubband transitions in 2D materials. We first lay the theoretical framework for intersubband transitions in TMDs by using ab initio DFT calculations. We then demonstrate their first experimental observation using scattering scanning near-field optical microscopy (s-SNOM). We employ a doping modulation technique that provides the necessary sensitivity to observe intersubband absorption within a single quantum well. Our measurement technique allows us to quantitatively observe intersubband absorption with a nanometer scale spatial resolution, which is the highest reported spatial resolution of intersubband transitions in any class of material. We perform spectrally resolved measurements, which are in good agreement with our theoretical calculations and show signatures of many-body interactions and non-vertical transitions due to the momentum provided by the sharp AFM tip apex. Finally, we investigate the interaction of intersubband transitions with graphene plasmons and hBN hyperbolic phonon polaritons by transfer matrix method and finite difference time domain simulations and fabricate various van der Waals heterostructures in order to experimentally explore these interactions.

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